/CDF/ANAL/EXOTIC/CDFR/6929

Searches for First Generation Leptoquarks in the eejj channel

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Abstract

This note describes the analysis update for search for first generation scalar leptoquarks.

The full CDF dataset up to the Summer shutdown of 2003 has been used, corresponding to about 200.0 pb^{-1} of run II data taken at $\sqrt{s}$ = 1960 GeV. The data have been reprocessed with software version 4.11.1 (REMAKE sample) and the signal efficiencies and background estimate has been revised and/or updated.

Leptoquarks are assumed to be pair produced and to decay into a lepton and a quark of the same generation. We will focus on the signature represented by two energetic electrons and two jets. We set an upper limit at 95% CL on the production cross-section as a function of the mass of the leptoquark. By Assuming (β = Br(LQ$\rightarrow$ eq)) = 1 and using the NLO theoretical estimate we reject the existence of scalar leptoquarks with mass below 230 GeV/c^2 .

Introduction

Leptoquarks are hypothetical color-triplet particles carrying both baryon and lepton quantum numbers and are predicted by many extension of the Standard Model as new bosons coupling to a lepton-quark pair[1]. Their masses are not predicted. They can be scalar particles (spin 0) or vector (spin 1) and at high energy hadron colliders they would be produced directly in pairs, mainly through gluon fusion or quark antiquarks annihilation. In figure 1 a typical production diagram is reported.

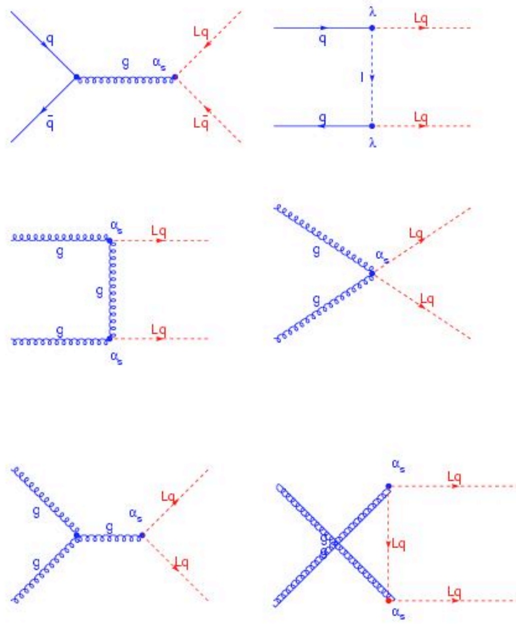

Figure 1

The couplings of the leptoquarks to the gauge sector are predicted due to the gauge symmetries, up to eventual anomalous coupling in the case of vector leptoquarks, whereas the fermionic couplings □ are free parameters of the models. In most models leptoquarks are expected to couple only to fermions of the same generations because of experimental constraints as non observation of flavor changing neutral currents or helicity suppressed decays. The production cross section for pair produced scalar LQ has been calculated up to NLO[1].The decay angular distribution of scalar leptoquarks is isotropical. The NLO cross section at s = 1960 GeV is reported in Table 0 for values of the LQ mass between 200 and 320 GeV/c^2. The scale has been chosen to be $Q^2 = M_{LQ}^2$ and the set of parton distribution functions is CTEQ4M[].

M_{LQ} (GeV/c^2)	□(NLO) [pb]
200	0.265E+00
220	0.139E+00
240	0.749E-01
260	0.412E-01
280	0.229E-01
300	0.129E-01
320	0.727E-02

Table 1 –*Theoretical cross section for pair production of LQ at s = 1960 GeV. Q = m(LQ)*

The cross section compared with the one at 1.8 TeV is reported in Figure 2

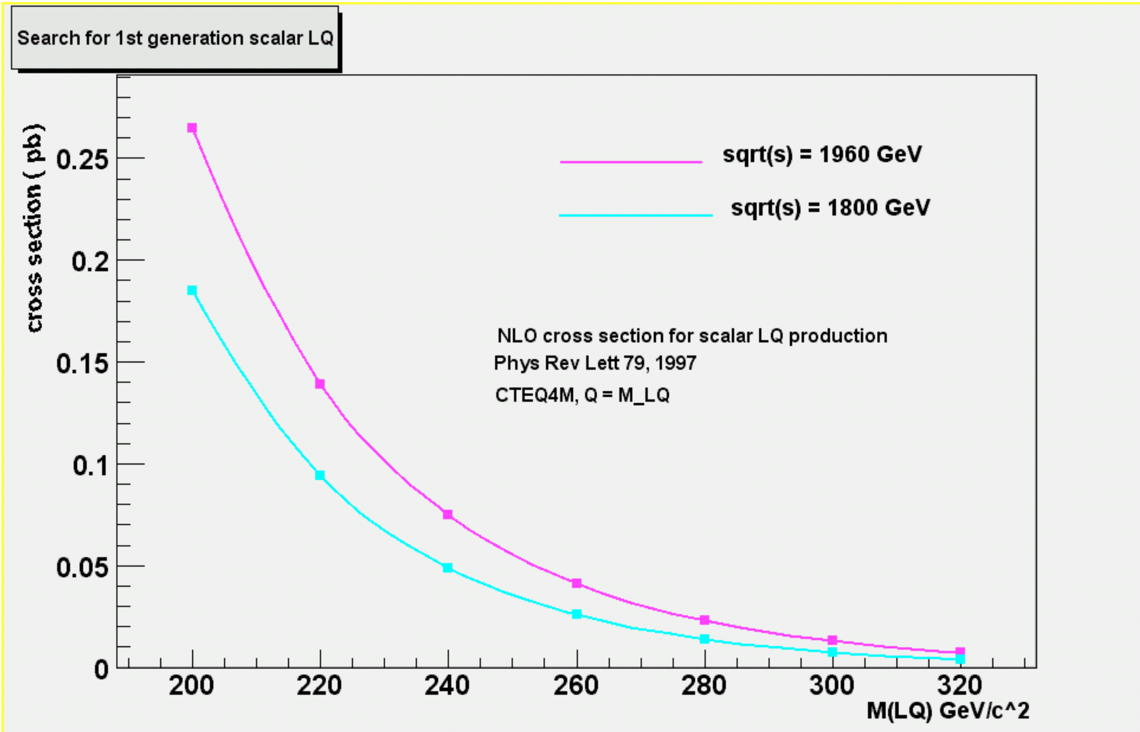

Figure 2

This analysis is focused on the search for first generation scalar leptoquarks S1, pair produced and decaying into eejj. The analysis strategy is a repetition of the run I analysis[2,3] and at this time improvements and optimization of cuts are not performed.

Current Limits

In table 1 the current limits on the first generation LQ are reported, both from CDF and D0.

1^{st} Gen	□	Scalar (GeV/c^2)
D0	1 0.5 0	231 (Run II) 204 (Run I) 98
CDF	1 0.5 0.5	230 (Run II) 202 (Run I) 166 (Run II)

Table 2 – *current limits on first generation LQ from the TeVatron*

Data sample and electron identification

The data sample used for this analysis is *btop0g* (inclusive electrons) stripped for the Top group from the inclusive high pt electron datasets. The sample is described in[4].
The L3 trigger dataset *(bhel08*) was reconstructed with offline version 4.8.4 and the events were filtered into *btop0g* using the following loose cuts:

- CdfEmObject.Pt > 9.0 GeV
- CdfEmObject.etCalMin > 18.0 GeV
- CdfEmObject.delX < 3.0
- CdfEmObject.delZMin < 5.0
- CdfEmObject.E/P < 4.0
- CdfEmObject.lshr < 0.3
- CdfEmObject.hademMax < 0.125

For the ELE_70 trigger:

- CdfEmObject.Pt > 15.0 GeV
- CdfEmObject.etCalMin > 70.0 GeV
- CdfEmObject.delX < 3.0
- CdfEmObject.delZMin < 5.0

A REMAKE version of *b0topg* was made where all the calorimeter-dependent objects were dropped in input as well as electron and muon reconstruction objects. The 4.8.4 tracks were refitted (using TrackRefitModule) without L00 hits, and electron and muon objects were remade picking up the refit tracks and run-dependent calorimeter corrections. The sample is described at http://www-cdf.fnal.gov/internal/physics/top/topdata/TopData_4111.html and corresponds to an integrated luminosity of 199.7 * 1.019 pb^{-1} (good runs between March 2002 and September, 2003 – runs 141544 to 168889) , selected following the *good run list without Silicon for electron*, version 4, as described in http://www-cdf.fnal.gov/internal/dqm/goodrun/v4/goodv4.html).
As for the Z' analysis, both the Electron_Central_18 and Electron_70 triggers were used, due to the complementary efficiency of the had/em cut.

The sample has been reduced by requiring events with at least 2 CdfEmObjects corresponding to electrons, satisfying the following criteria:
One central tight electron and a second central loose or plug.
The central electron requirements are the following:

- E_T > 25 GeV
- p_t > 15 GeV

- hadem < 0.055 + 0.00045 * E
- E/p < 4 (for E_T < 100 GeV)
- |DeltaX | < 3.0 cm
- |DeltaZ | < 5.0 cm
- lshr <= 0.2
- FIDELE == 1
- isolation ratio < 0.1

The second central electron is required to satisfy the same requirements but the isolation cut, relaxed to 0.2.

The Plug electron requirements are listed below:

- E_T > 25 GeV
- isolation ratio < 0.1
- E_{had}/E_{em} < 0.055 + 0.00045 * E
- $\chi^2_{3x3} < 10$
- Fiducial cut $1 < |\eta| < 3$

These electron identification cuts are also used in the Z'[5,6] analysis and the efficiencies are reported in Table 3.

CDF Run II Preliminary (200 pb^{-1})

Cut	Number of candidate events	Number of background	Efficiency (%)
$Iso < 0.1$	4686	146	97.2± 0.2
$Iso < 0.2$	4912	204	99.0± 0.1
$E_{had}/E_{em} < 0.055 + 0.00045 \times E$	4962	252	99.0± 0.1
$E/P < 4.0$(for $E_T < 100$)	5357	562	99.9± 0.0
$\|\Delta X\| < 3.0$	5210	508	98.9± 0.1
$\|\Delta Z\| < 5.0$	5299	532	99.7± 0.1
$L_{shr} < 0.2$	4988	304	98.7± 0.1
Tight central overall(ε_T)	4406	108	94.5± 0.2
Tight central overall(ε_L)	4569	120	96.2± 0.2
$\varepsilon_{CC}(= 2 \cdot \varepsilon_T \cdot \varepsilon_L - \varepsilon_T^2)$			92.4± 0.4

Table 3 – ID Efficiencies for central electrons

CDF Run II Preliminary (200 pb^{-1})		
Cut	candidate events	Efficiency (%)
$Iso < 0.1$	5621	92.8± 0.3
$E_{had}/E_{em} < 0.055 + 0.00045 \times E$	5837	96.4± 0.2
$\chi^2_{3\times3}$	5161	85.2± 0.5
Plug overall (ε_P)	5075	83.8± 0.5
ε_{CP} $(= \varepsilon_T \cdot \varepsilon_P)$		79.2± 0.5

Table 4 - ID efficiencies for plug electrons

Acceptance calculation

We generated 5000 events samples of scalar leptoquarks pair decaying into *eq* for M_{LQ} in the range 200 to 320 GeV/c^2 using Pythia[10]. The samples have been generated to simulate realistic beam conditions, emulating run number 151435 and using the following talk-to for the full beam position:

```
talk GenPrimVert
  BeamlineFromDB set false
  sigma_x        set  0.0025
  sigma_y        set  0.0025
  sigma_z        set 28.0
  pv_central_x   set -0.064
  pv_central_y   set  0.310
  pv_central_z   set  2.5
  pv_slope_dxdz  set -0.00021
  pv_slope_dydz  set  0.00031
exit
```

The samples were generated with $Q^2 = M_{LQ}^2$ and the MRS-R2 pdf set[12]. The samples were simulated with cdfSim version 4.9.1 and Production 4.9.1 was ran on them.
In figure 3-5 the E_T distributions of the decay products of the Leptoquark are plotted, for different values of the mass of the leptoquark and after reconstruction.

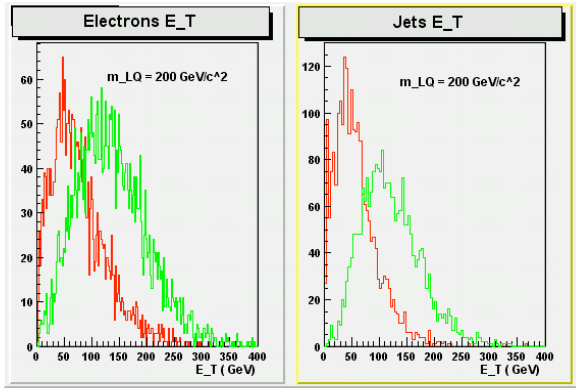

Figure 3

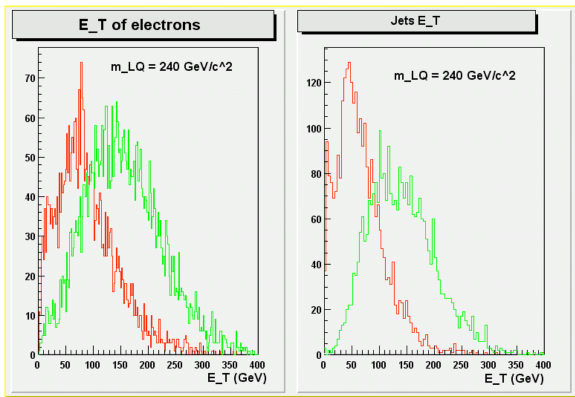

Figure 4

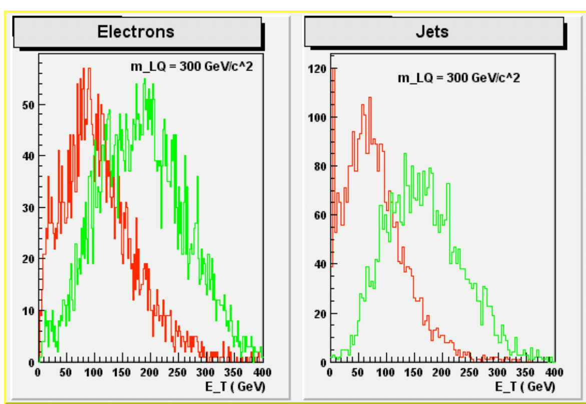

Figure 5

The analysis cuts are the following:

- 2 electrons with $E_T > 25$ GeV
- 2 jets with $E_T(j1) > 30$ and $E_T(j1) > 15$ GeV
- Removal of events with $76 < M_{ee} < 110$

- $E_T(j1) + E_T(j2) > 85$ GeV && $E_T(e1) + E_T(e2) > 85$ GeV
- $((E_T(j1) + E_T(j2))^2 + (E_T(e1) + E_T(e2))^2) > 200$ GeV

The last cut was shown in run I to discriminate between signal and background, as shown in Figure 6. In Figures 7 the sum of the electrons E_T is plotted against the sum of the 2 jets E_T for signal, DY + 2 jets and tt after selecting 2 electrons and 2 jets.

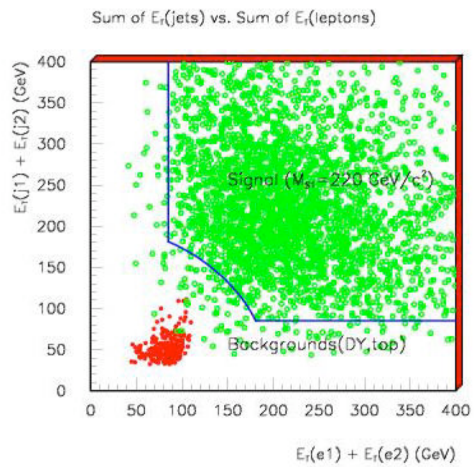

Figure 6 – *Sum of E_T(jets) vs Sum of E_T(electrons) – run I simulation*

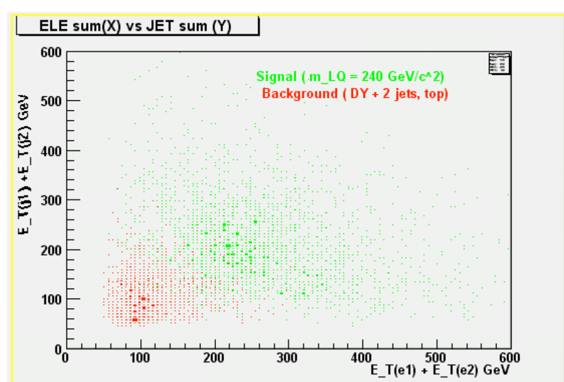

Figure 7 – *Sum of E_T(jets) vs Sum of E_T(electrons) – run II simulation*

The analysis cuts efficiencies are calculated relatively to the number of events having 2 cdfEmObjects with track id different from 0 (to exclude photons), matching the generator level electrons. They are reported in Figure 8 and Table 4. The efficiencies are then folded with the electron ID efficiencies reported in Table 2, the z vertex cut efficiency[7] (0.952 ±001 (stat) ±005 (sys)) and the trigger efficiency[9] (0.991 ±001) . We have verified that the electron identification efficiencies for 2 central electron for the signal (M_{LQ} = 240 GeV/c^2) are of the same order of magnitude of the ones calculated from real Z data. ε_T = 0.875 ±0.006, while ε_L = 0.882±0.006. The combined efficiency is: $2\varepsilon_T\varepsilon_L - \varepsilon_T\varepsilon_T$ = 0.777 ±0.008. The slightly lower efficiency can be attributed to a reduced efficiency of the isolation cut in an environment denser in jets than $Z\rightarrow e^+e^-$.

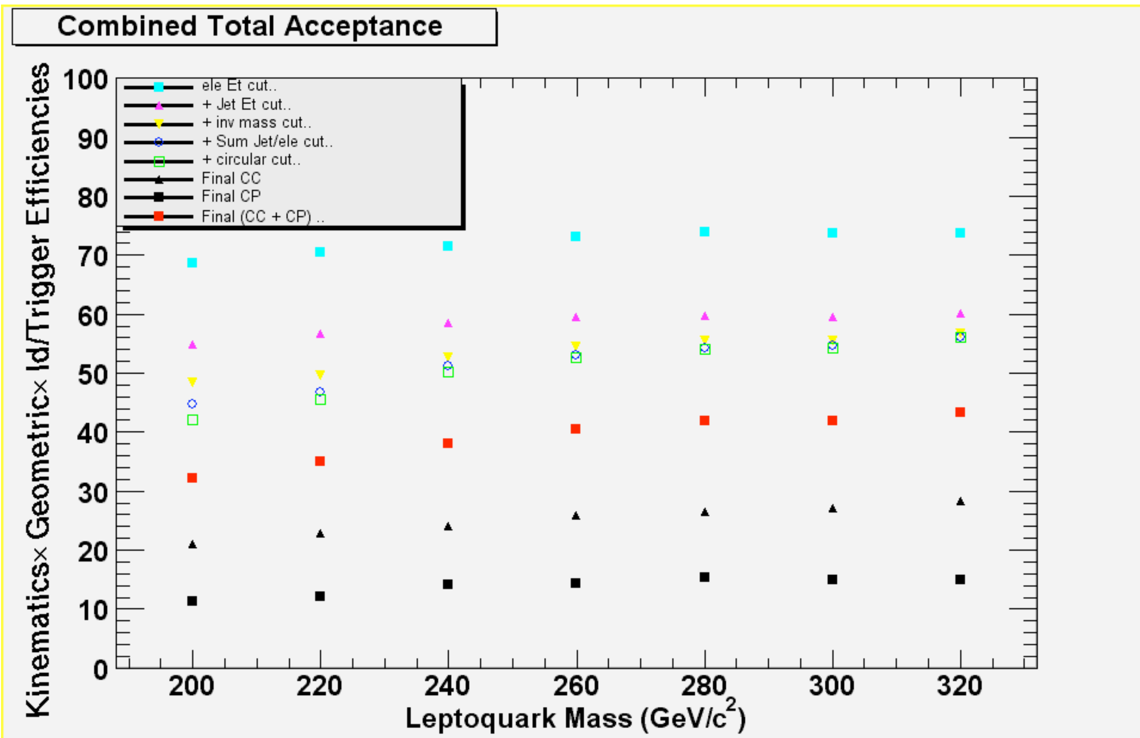

Figure 8 – *kinematical efficiency as function of the leptoquark mass*

M_{LQ} (GeV/c^2)	200	220	240	260	280	300	320
2 ele with E_T > 25 GeV	0.70±0.006	0.71±0.005	0.714±0.005	0.731±0.005	0.738±0.004	0.737±0.004	0.737 ±0.004
2 jets with E_T > 30, 15 GeV	0.55±0.009	0.56±0.007	0.58±0.008	0.59±0.007	0.597±0.007	0.59±0.007	0.60± 0.006
M_{ee} removal cut	0.483±0.009	0.496±0.008	0.527±0.008	0.545±0.008	0.555±0.008	0.555±0.008	0.567± 0.008
$\Sigma(E_T(ele_i))$ > 85 GeV & $\Sigma(E_T(jet_i))$ > 85 GeV	0.447±0.009	0.467±0.008	0.512±0.009	0.531±0.008	0.542±0.008	0.546±0.008	0.561± 0.008
$\Sigma(E_T(ele_i)+ E_T(jet_i))$ > 200	0.420±0.009	0.456±0.008	0.501±0.008	0.526±0.008	0.540±0.008	0.542±0.008	0.560± 0.008

Table 4 – *Total* (CC + CP) *kinematical efficiency as function of the leptoquark mass*

The expected number of events of signal in 203 pb^{-1} given the above efficiencies and the NLO theoretical cross section for different value of the renormalization/factorization scale, is reported in the Table below:

Mass (GeV/c^2)	n Theory CTEQ4M (pb) $Q^2 = M^2_{LQ}/4$	n Theory CTEQ4M (pb) $Q^2 = 4M^2_{LQ}$
200	18.9	15.3
220	10.7	8.7
240	6.32	5.1
260	3.7	2.9
280	2.13	1.7
300	1.2	0.95
320	0.7	0.55

Table 5 – *Expected number of signal events in 203 pb^{-1}*

After our selection cuts 4 events are left. In Table 5 we report the number of events surviving each kinematical cut.

Number of events with 2 electrons with $E_T > 25$ GeV	12461
2 jets with $E_T(j1) > 30$ GeV and $E_T(j1) > 15$ GeV	138
removal of events with $76 < M_{ee} < 110$ GeV	46
$E_T(j1) + E_T(j2) > 85$ GeV && $E_T(e1) + E_T(e2) > 85$ GeV	21
$((E_T(j1) + E_T(j2))^2 + (E_T(e1) + E_T(e2))^2) > 200$ GeV	4

Table 5 – *List of events passing the selection cuts*

Backgrounds

The main backgrounds is due to $\gamma/Z\rightarrow ee$ events accompanied by jets due to radiation. The main component of this background is eliminated by cuts on M_{ee} around the mass of the Z boson and the ΣE_T cuts. However there are still events from the DY continuum and Z events that fail the cuts due to mis-measurement. We studied the distribution of this background by generating the process Z + 2 jets with Alpgen[11] and using the MC parton generator mcfm[13] to obtain the NLO cross section.
Another source of background is represented by tt production where both the W decay into $e\nu$. Other backgrounds from bb, $Z\rightarrow\tau\tau$, WW are expected to be negligible due to the electron isolation and large electron and jet transverse energy requirements. The expected number of DY + 2 jets events in 203.2 pb^{-1} is 1.89 ± 0.44. The expected number of tt events is 0.35 ± 0.03 events. To normalize simulated events to data we used the theoretical cross section for tt, $\sigma(tt)\times Br(W\rightarrow e\nu) = 0.0739$ pb, and the theoretical cross section for Z/γ+ 2 jets obtained with mcfm.

The total number of expected events of background is 2.24 +/- 0.55

Another source of background is represented by events where a jet fakes an electron (fakes). We used 2 methods to estimate the fakes background. The first is the isolation method, the second is the one based on the counting of same sign events to estimate the contamination from dijets faking electrons (this last method is only valid for central-central electrons, as we don't use tracking information for plug electrons).

The isolation method relies on the assumption that since jets are produced in association with other particles, the isolation fraction of a jet will be generally larger than the one corresponding to an electron. The phase space corresponding to the 2 electrons isolation fractions is divided in 4 regions:

For central-central :

Region A) $Iso_1^{central} < 0.1$, $Iso_2^{central} < 0.2$;

Region B) $Iso_1^{central} < 0.1$, $0.2 < Iso_2^{central} < 0.4$;

Region C) $0.2 < Iso_1^{central} < 0.4$, $Iso_2^{central} < 0.2$;

Region D) $0.2 < Iso_1^{central} < 0.4$, $0.2 < Iso_2^{central} < 0.4$;

For central-plug:

Region A) $Iso_1^{central} < 0.1$, $Iso_2^{plug} < 0.1$;

Region B) $Iso_1^{central} < 0.1$, $0.2 < Iso_2^{plug} < 0.4$;

Region C) $0.2 < Iso_1^{central} < 0.4$, $Iso_2^{plug} < 0.1$;

Region D) $0.2 < Iso_1^{central} < 0.4$, $0.2 < Iso_2^{plug} < 0.4$;

The following assumptions are made:

There is no correlation between the isolation of the 2 electrons;

Signal events are only in region A all events in the other regions are background events.

If we assume that the ratio of A to B equals the ratio of C to D for QCD events, we can estimate how many QCD events we will have in the A region.

The second method counts the number of same sign events. The assumption is made that the probability of negative charge found in the highest P_T track in a jet is roughly the same as for positive charge.

After comparing the 2 methods we estimate $0^{+0.7}_{-0}$ fake events in CC and 3.96± 1.98 in CP.

The final background estimate is : 6.24 +/- 3.5.

We also checked that the events we are left before requiring the jets and the following analysis cuts are consistent with the production of Z.

Z boson candidates are selected by requiring $70 \text{ GeV} < M_{ee} < 110 \text{ GeV}/c^2$ (as in the Z' analysis) and the cross section is calculated from the following formula:

$$\sigma \cdot Br(p\bar{p} \to Z \to e^+e^-) = (N_Z - N_{BG})/(A_Z \cdot \varepsilon_{ID} \cdot \varepsilon_{trig} \cdot \varepsilon_{z0} \cdot L)$$

Using the values listed in the Table below we obtain for the Z cross section a values consistent with the theoretical prediction of 250 pb.

	Central-Central	Central-Plug
Acceptance	10.1 ± 0.1%	18.3 ± 0.7%
ID efficiency	92.4 ± 0.4%	79.2 ± 0.4%
Trigger Efficiency	99.9 ± 0.1%	96.8 ± 0.1%
z_0 efficiency	95.2 ± 0.5%	95.2 ± 0.5%
Observed number of events	4568	6954
Estimated background	91.6	194.4
Integrated Luminosity	203.3. ± 12.2	
Z boson cross section	247±15.5	248±15.8

Table 6 – *parameters used in the calculation of the Z cross section*

Systematic Uncertainty

The following systematic uncertainty is considered:

- Luminosity: 6%
- Acceptance
  - pdf 4.3% (from run I)
  - statistical error of MC 2.2%
  - Jet energy scale < 1%
- Electron ID efficiency[5,6]
  - statistical error of $Z \to e^+e^-$ sample: 0.8%
- Event vertex cut : 0.5%[7]

Adding the above systematic uncertainty in quadrature will give a total systematic uncertainty of about 8.5%. The total relative uncertainty on the acceptances varies from 13% to about 8%, decreasing monotonically with the increase in the LQ mass.
Final signal efficiencies and uncertainties are reported in table 7.

Mass LQ (GeV/c^2)	**Acceptance** (%)	**Abs stat**	**Abs sys**	**Relative total uncertainty**
200	**32.24**	**0.85**	**4.57**	**0.14**
220	**35.07**	**0.79**	**4.13**	**0.12**
240	**38.11**	**0.80**	**3.8**	**0.10**
260	**40.4**	**0.82**	**3.7**	**0.09**
280	**41.8**	**0.84**	**3.6**	**0.087**
300	**41.9**	**0.84**	**3.5**	**0.084**
320	**43.3**	**0.84**	**3.4**	**0.080**

Table 7 – final signal efficiencies and errors

Cross section Limit

The production cross section σ of the process S1S1$\rightarrow$ eejj can be written as follows:

$$\sigma \times Br(S1S1 \rightarrow eejj) = \sigma \times \beta^2 = N/(\varepsilon \times L),$$

where N is the number of observed events on data after our selection, ε is the total selection efficiency as a function of M_{LQ} and L is the integrated luminosity. As we found no candidate events in our selection, we set a 95% C.L. upper limit on the cross section as a function of M_{LQ} defined as:

$$\sigma^{lim} = N^{lim}/(\varepsilon \times L \times \beta^2)$$

The limit was calculated using bayes[14].
In Table 7 we report the values of the limit cross sections in eejj for each M_{LQ} and for β = 1 and the theoretical calculations at NLO for pair production of scalar LeptoQuarks at the TeVatron done using CTEQ4M pdf and for different choices of the scale. In Figure 8 the limit cross-section as function of M_{LQ} is compared with the theoretical expectations for β = 1. At the intersection point between experimental and theoretical curves we find the lower limit on M_{LQ} at 230 GeV/c^2.

Mass (GeV/c^2)	95%CL σ (pb)	σ Theory CTEQ4M (pb)	σ Theory CTEQ4M (pb)
		$Q^2 = M^2_{LQ}/4$	$Q^2 = 4M^2_{LQ}$
200	0.1072	0.2890	0.2330
220	0.0967	0.1510	0.1220
240	0.0873	0.0815	0.0657
260	0.082	0.0449	0.0360
280	0.0789	0.0250	0.0200
300	0.0784	0.0141	0.0112
320	0.0759	0.00799	0.00629

Table 7 – *Values of the upper limits at 95% CL of the production cross section of first generation leptoquarks decaying into eejj channel as a function of M_{LQ}. The last 2 columns on the right report the result of the theoretical calculations at Next-To-Leading order with CTEQ4M for different choices of the scale, multiplied by a factor β^2 = 1.*

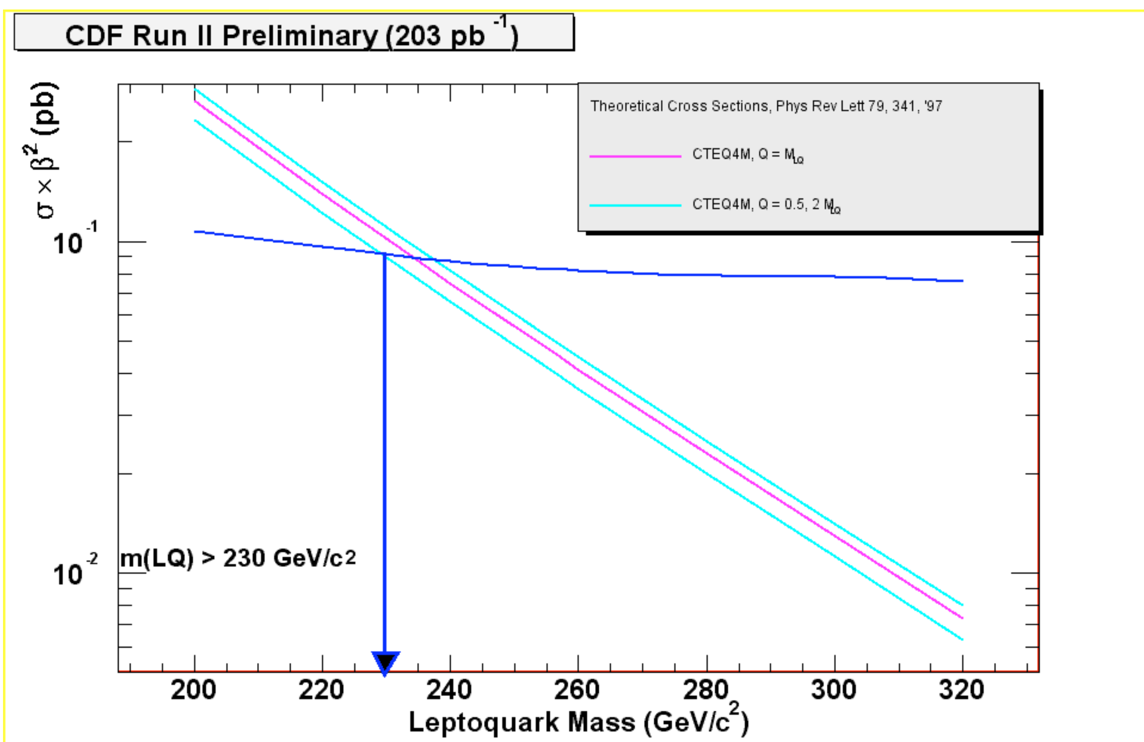

Figure 8- *Limit cross section as a function of M_{LQ} compared with the theoretical expectations calculated at NLO accuracy. At the intersection points between experimental and theoretical curves we find a lower limit on M_{LQ} at 230 GeV/c^2*

Conclusions

We have updated the Winter 2003 result relative to searches for first generation scalar leptoquarks decaying into electrons and jets. A preliminary 95% CL cross section lower limit as a function of M_{LQ}, for leptoquarks decaying with 100% branching ratio into eq is set by comparison to the theoretical predictions for leptoquark pairs production at the TeVatron. By using the theoretical estimate, we can reject the existence of a scalar leptoquark with mass lower than 230 GeV/c^2 for $\beta = 1$.

Appendix – Differences with the previous analysis

The result presented in this note does not improve the previous result presented in March 2003. This is due to an erroneous definition of the efficiency for CC electrons in the previous analysis. As a consequence the kinematical + geometrical acceptances for the signal were overestimated at that time.
The way we calculated the signal kinematical and geometrical acceptance is the following: we select events were the HEPG electron is matched in a $\Delta R = (\Delta\eta^2 - \Delta\phi^2)$ cone to the reconstructed electron.
Events are further selected if the fall in 3 categories (geometrical acceptance):
events with 2 central electrons (fidele == 1)
events with 2 central-plug electrons ($1 < |\eta| < 3$)
events with 2 plug-plug electrons ($1 < |\eta| < 3$)
Weights are derived for the 3 contributions (we notice incidentally that contribution 3 is extremely small, given the nature of the LQ production, but we include the category for completeness) normalizing the number of events in each of the three categories to their sum.
The kinematical cuts are applied to al l the events passing the geometrical requirement. The resulting number of events is normalized to the number of matching events and weighted according to the CC or CP population.
In the previous analysis, the weighting procedure was not applied properly and the sum of all the contributions was used instead of only CC (and subsequently multiplied by ID/trigger efficiency for CC). Since we were looking at data in the CC region only (and observed 0 events) the cross section limit was then overestimated. Using CC only

acceptances in fact would have given a mass limit of order 205 GeV/c^2. On the other hand we checked how many events, given the good run list used in March 2003, we would have seen in the CP category and we found that also the number of CP events observed was 0. This would have made the limit reach 220 GeV/c^2.

References

1) Pair Production of scalar LeptoQuarks at the TeVatron, M. Kramer et al., Phys Rev Lett 79, 341, 1997.
2) Search for first generation leptoquarks pair production , A. Amadon, C. Grosso-Pilcher and F. Strumia, CDF/ANAL/EXOTIC/CDFR/4126, July 1997
3) Searches for First Generation Leptoquarks in the eeqq and enuqq channels, Federica Strumia, Allan Clark,Lorenzo Moneta, Xin Wu and Carla Grosso-Pilcher CDF/ANAL/EXOTIC/CDFR/4873
4) Description of data samples for Top and Electroweak groups for Winter 2003, Evelyn J. Thomson, CDF/DOC/TOP/PUBLIC/6265
5) Randall-Sundrum resonance searches in high mass Run I dilepton data, Tracey Pratt, Koji Ikado, Kaori Maeshima, Todd Huffman CDF/ANAL/EXOTIC/CDFR/6117
6) Search for Resonances in High Mass Dielectron Koji Ikado, Kuni Kondo, Kaori Maeshima, Tracey Pratt CDF/ANAL/EXOTIC/CDFR/6080
7) Event |Zvtx| < 60 cm Cut Efficiency for Run II W.K. Sakumoto and A. Hocker CDF/ANAL/ELECTROWEAK/CDFR/6331
8) Z^{0} to electrons Cross Section measurement with Run II data Young-Kee Kim, Giulia Manca CDF/ANAL/ELECTROWEAK/CDFR/6281
9) Trigger Efficiencies for High P_T Electrons Young-Kee Kim, Jason Nielsen, Lauren Tompkins, Greg Veramendi CDF/DOC/ELECTRON/CDFR/6234
10) http://www.thep.lu.se/~torbjorn/Pythia.html
11) http://mlm.home.cern.ch/mlm/alpgen/
12) http://consult.cern.ch/writeup/pdflib/
13) http://mcfm.fnal.gov/
14) Poisson Upper Limits Incorporating Uncertainties in Acceptance and Background John Conway Kaori Maeshima CDF/PUB/EXOTIC/PUBLIC/4476